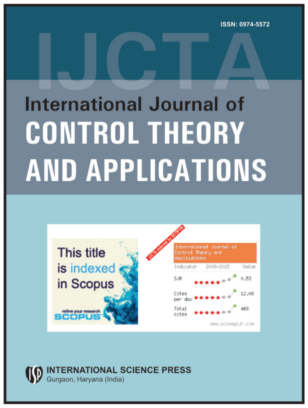

International Journal of Control Theory and Applications

ISSN : 0974-5572

Volume 10 • Number 16 • 2017

Harmony Search Algorithm for Management of Contingencies based on Optimal Reallocation of Generators

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Abstract: Stable operation of the power systems in both normal and contingency condition is of vital importance. A proper method need to be designed to stop serial contingencies in power systems. In this paper, a combined index based strategy for the optimal placement of Thyristor Controlled Series Compensator (TCSC) and optimal reallocation of generators using Harmony search Algorithm has been proposed for contingency management. The TCSC has been placed on the basis of an index which is a combination of Line Utilization Factor (LUF) and Fast Voltage Stability Index (FVSI). A multi objective function has been chosen for tuning the generators. The multi-objective function includes voltage deviation, active power generation cost and transmission line loss. The results obtained have been compared with a state of art method, i.e., genetic algorithm. The proposed method has been tested and implemented on an IEEE 30 bus system.

Keywords: Optimal Reallocation; TCSC; Harmony search Algorithm; Voltage Stability.

1. INTRODUCTION

Due to the increase in the competition in the electrical industry, optimum usage of the available power has become obligatory. Conversely, due to rise in the power flow, transmission lines are continuously facing a problem of congestion because of carrying power at their extreme transmission limits and sometimes higher. Continuous overloading of the transmission lines can risk the security, reliability and stability of the power systems. Optimal power flow is a method of optimizing an objective function in the presence of operational constraints by the method of nonlinear programming. Many methods have been developed so far to solve the OPF problem. Metaheuristic methods are one of the most recent methods used for the OPF problem.

Nanda Kumar and Dhanasekaran proposed optimal power flow method to determine the steady state operation point which minimizes multiple objectives and at the same time improves the system performance [1]. Vijay Kumar demonstrated the effect of TCSC on congestion of transmission lines by optimal power flow method using Genetic algorithm [2]. Rao and Gundavarapu have used OPF technique in the presence of SVC for the improvement of network security under contingency condition [3]. The performance of BAT and Firefly algorithm have been compared to determine the optimal location and size of Static VAR Compensator (SVC) in a power system to improve voltage stability for a multi objective function [4]. Mishra and Gundavarapu proposed the placement of Interline Power Flow Controller (IPFC) for the reduction of congestion of the transmission lines [5]. The Line severity index used is found to a very efficient method of estimation of loading of the transmission lines.

Ya-Chin have used multi-objective Particle Swarm optimization method for the installation of SVC to improve transmission system loading margin (LM) to a certain degree and reduce network expansion cost [6]. Shaheen has used computational intelligence method namely DE has been used to find the optimal location and size of UPFC on the basis of performance index for N-1 contingency condition [7]. Mishra and Gundavarapu proposed placement of IPFC using an index which is a combination of real power performance index and line stability index, for management of contingency [8]. The IPFC was then tuned using Differential Evolution (DE). The proposed index is found to be a more accurate measure of severity in comparison to the individual indices. It is also found that use of line voltage stability index is a good option for the measurement of voltage stability for series devices. Optimal reallocation of generators is necessary for the optimal utilization of the available power system resources. The advantages of the method can be further improved by the placement of FACTS devices. Series FACTS devices are most suitable for enhancing the transmission capabilities. The FACTS device should be correctly placed in the system in order to enhance its effectiveness. Harmony Search Algorithm [9] was introduced in the year 2001. This algorithm has been implemented in different fields like economic load dispatch [10], mitigation of blackout [11] and AGC optimization of multi-unit power systems [12].

In this paper, optimal reallocation of generators has been proposed for the management of contingency condition in the power systems. Harmony search Algorithm has been used for the optimal power flow in the presence of TCSC. The optimal reallocation of generators has been done for a multi-objective function, specifically, reduction in voltage deviation, reduction of fuel cost and reduction in transmission line loss. The real and reactive power generation values and voltage limits for buses are taken as constraints, during the optimization. The results of optimal tuning without and with TCSC have been compared to prove the effectiveness of the proposed method.

2. PROPOSED COMBINATORY INDEX

A combined index is formulated using LUF and FVSI indices as given in equation 1.

$$CI = W_1 \xi I_1 + W_1 \times I_2 \tag{1}$$

where, w_1 and w_2 are the weighting factors.

I_1 is the Line Utilization Factor is an index used for determining the congestion of the transmission lines.

LUF is given by equation (2)

$$I_1 = \frac{MVAij}{MVAij^{max}} \tag{2}$$

MVAij(max): Maximum MVA rating of the line between bus *i* and bus *j*.

MVAij: Actual MVA rating of the line between bus *i* and bus *j*.

LUF gives an estimate of the percentage of line being utilized.

Fast Voltage Stability Index Factor (FVSI) calculates the voltage stability of a given bus under any loading conditions. It is defined as follows:

I_2 is the Fast Voltage Stability Index (FVSI) given by equation (3)

$$I_2 = 4\frac{Z^2 Q_j}{V_i^2 X} \tag{3}$$

where, Z is the impedance of line.

X is the line reactance.

V_i is the voltage at the sending end.

Q_j is the reactive power at the receiving end.

Both LUF and FVSI have stable region, when the value of the index is less than 1.

3. HARMONY SEARCH ALGORITHM

Harmony Search (HS) is a population based metaheuristic algorithm inspired from the musical process of searching for a perfect state of harmony, proposed by Zong Woo Geem in 2001. In the HS algorithm,

- musician is equivalent to decision variable;
- plays is equivalent to generates;
- a note is equivalent to a value;
- for finding a best harmony is equivalent to Global optimum.

The pitch is equivalent to fitness value

3.1. Parameters of HSA

HMS = size of the harmonic memory.

HMCR = rate of choosing a value from the harmony memory (Harmony Memory Considering Rate)

PAR = rate of choosing a neighboring value (Pitch Adjustment Rate)

δ = amount between two neighboring values in discrete Candidate set.

fw (fret width) = maximum change in pitch adjustment.

Table 1
Optimal Range of Harmony Search Parameters

Parameters	*Optimal Range*
HMS	1 – 100
HMCR	0.7 – 0.99
PAR	0.1 – 0.5
Fw	0.1

Harmonic memory consisting of HMS vectors is generated randomly as $x_i = x_{ij}$ where, $j = 1$ ... HMS and $j = 1$ ... n.

$$x_{ij}^{new} = x_{ij}, x_{ij} \in (x_{1j}, x_{2j}, ..., x_{HMS}) \tag{4}$$

$$x_{ij}^{new} = x_{ij} \pm \text{rand}(0, 1)\text{BW} \tag{5}$$

$$x_{ij} = l_{ij} + (u_{ij} - l_{ij}) \tag{6}$$

$$x^{worst} = x^{new} \tag{7}$$

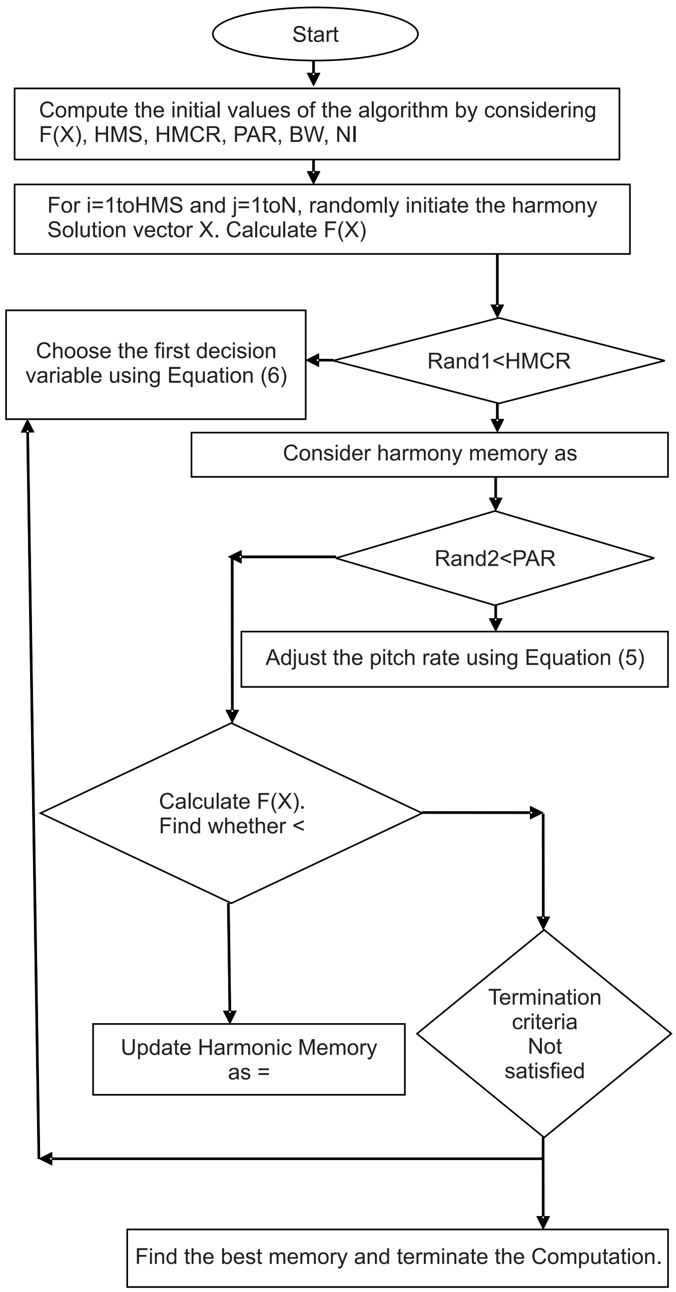

Figure 1: Flow Chart depicting the Harmony Search Algorithm

4. RESULTS AND DISCUSSION

Contingency analysis for the IEEE 30 bus system is performed and the values of the combinatory index have been tabulated in Table 2. It is observed that removal of line 15-23 causes maximum stress to the system indicated by the maximum CI value of 0.2828 p.u. Hence, *n*-1 contingency for line 15-23 and TCSC at line 9-10 has been considered for the study as shown in Figure 2.

Table 2
Severity of lines for various line outages in descending order of CI

Line Outage		*Severe line*		*CI*
FB	*TB*	*FB*	*TB*	
15	23	9	10	0.2828
4	12	9	10	0.2569
28	27	9	10	0.2326
4	6	4	12	0.2283
6	10	9	10	0.2102
3	4	9	10	0.2047
12	15	9	10	0.1988
25	27	9	10	0.1966
6	28	9	10	0.1925
12	16	9	10	0.1922
15	18	9	10	0.1896
12	14	9	10	0.1885
16	17	9	10	0.1877
24	25	9	10	0.1876
18	19	9	10	0.187
27	30	9	10	0.1869
6	7	9	10	0.1867
27	29	9	10	0.1866
14	15	9	10	0.1861
29	30	9	10	0.1861
10	21	4	12	0.1853
23	24	9	10	0.1849
21	23	9	10	0.1833
6	9	9	10	0.1832
19	20	9	10	0.1818
10	22	9	10	0.1818
22	24	9	10	0.1818
10	20	9	10	0.1813
10	17	4	12	0.1783

The real power generation of the system and at individual generators, real and reactive power loss, voltage deviation and real power generation cost for HS-OPF without TCSC, GA-OPF without TCSC, HS-OPF with TCSC and GA-OPF with TCSC have been compared in Table 3. It is observed that harmony search is much more suitable for the multi-objective optimization problem chosen in comparison to GA. Also it is observed that OPF in the presence of TCSC is much more effective in comparison to without TCSC. Thus, the device proves to be highly effective for the optimization of the generators.

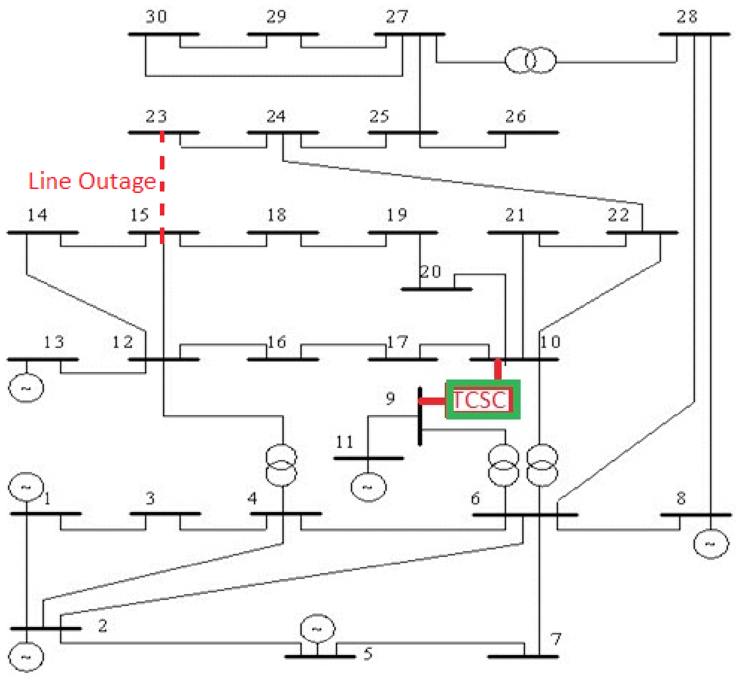

Figure 2: IEEE 30 bus system with15-23 contingency

Table 3: Comparison of Real power losses, Cost and Voltage deviation for without and with line outage with TCSC placed at 9-10

Condition	*Parameters*		*HS OPF without TCSC*	*GA-OPF without TCSC*	*HS OPF with TCSC*	*GA-OPF with TCSC*
Without Contingency	Real power generation (MW)	PG1	135.5568	126.6562	92.7718	131.3789
		PG2	32.6893	27.3374	32.6893	12.9481
		PG5	29.415	27.3348	29.415	23.945
		PG8	42.8081	21.3279	42.8081	19.1834
		PG11	40.5583	84.8224	40.5583	96.9945
		PG13	10	3.9926	50	5.0686
	Total Real power generation (MW)		291.0275	291.4713	289.3474	289.5185
	Real power losses (MW)		7.6274	8.0713	5.9474	6.1185
	Reactive power loss (MVAR)		19.38	35.35	8.26	25.59
	Total generation cost ($/hr)		1360.7	1366.9	1254.3	1259.9
	Voltage Deviation (p.u.)		1.9507	2.5013	0.4122	0.4227
With 15-23 line Contingency	Real power generation (MW)	PG1	135.565	134.2784	133.8937	131.4069
		PG2	32.6893	12.9481	32.6893	12.9481
		PG5	29.415	23.945	29.415	23.945
		PG8	42.8081	19.1834	42.8081	19.1834
		PG11	40.5583	96.9945	40.5583	96.9945
		PG13	10	5.0686	10	5.0686
	Total Real power generation (MW)		291.0357	292.418	289.3644	289.5465
	Real power losses (MW)		7.6356	9.0179	5.9644	6.1464
	Reactive power loss (MVAR)		19.41	46.04	8.44	25.98
	Total generation cost ($/hr)		1360.7	1370	1254.4	1260
	Voltage Deviation (p.u.)		1.9548	2.8728	0.5061	0.5822

Figure 3 compares the value of various parameters without contingency and with contingency, with TCSC placement and sizing. It is observed that the severity of the system increases due to contingency. Optimal placement and tuning of the TCSC with algorithm greatly reduces the severity.

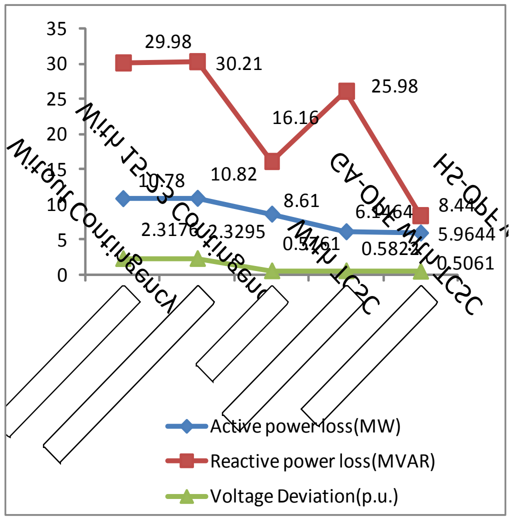

Figure 3: Comparison of results without contingency & with 15-23 contingency

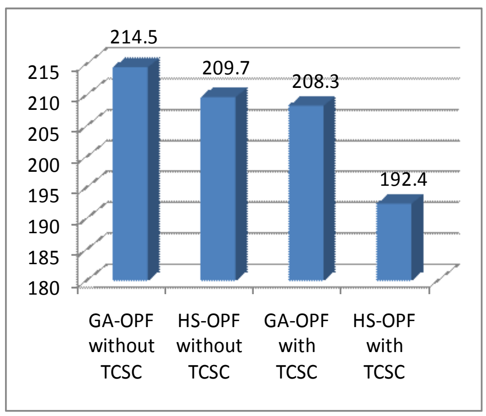

Figure 4: Comparison of multi objective function value with different methods under 9-10 contingency

In Figure 4, the multi-objective function values have been compared, HS seems to give a lower value of 192.4 p.u. in comparison to that of GA which is 208.3 p.u. Parameters of TCSC are shown in Table 4.The voltage profile of the 30 bus system for OPF without and with TCSC has been compared in Figure 5. The voltage profile of the system improves greatly when Harmony search OPF is performed in the presence of TCSC.

Table 4
TCSC Parameters

Method	*TCSC location (from bus no- to bus no)*	*TCSC Parameters*
NR with TCSC	9 – 10	X = 0.1, P_{TCSC} = 0.3854, Q_{TCSC} = 0.0124
HS Algorithm based Optimal Power Flow	9 – 10	X = 0.02, P_{TCSC} = 0.4318, Q_{TCSC} = 0.1985

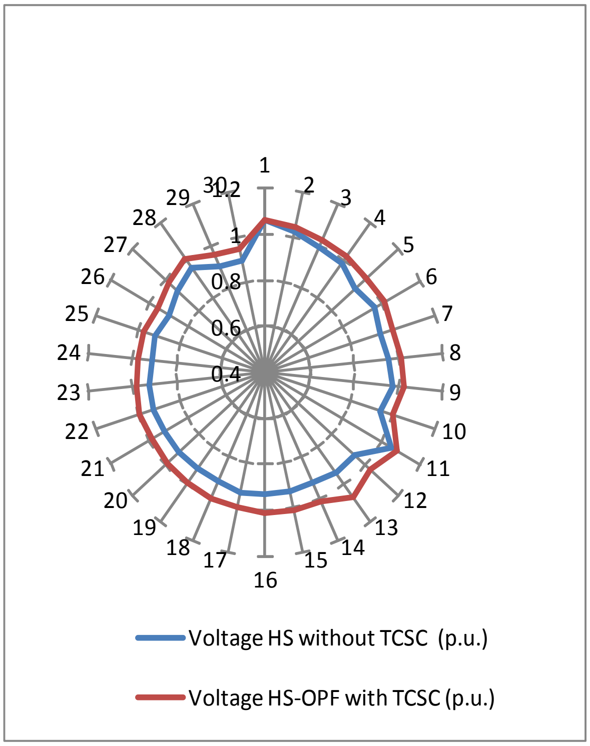

Figure 5: Comparison of Bus Voltages Using HS- Opf Without and With TCSC

5. CONCLUSIONS

Optimal reallocation of generators is an essential requirement of the present day power systems. In this paper,

- Optimal reallocation of generators with a TCSC has been suggested for optimal utilization of the power system resources and reduction of generation cost. The proposed method has been tested on an IEEE 30 bus system.
- Harmony search algorithm has been used to optimize the generators for the multi-objective function, viz., decrease in voltage deviation, fuel cost and transmission line loss considered.
- The reductions in the values of combinatory index specify that the placement of TCSC is highly effective in reduction of severity of the system. Although, TCSC is a series device, optimal reallocation of the generators and tuning of the device with harmony search algorithm also improves the voltage profile.
- The performance of the proposed methodology is also tested under severe system conditions. A line contingency condition has been considered for the purpose.
- The proposed method has been found to be an optimum key to the issues related to the power system performance in normal and severe system conditions, as depicted by the improvement in the values of the power system parameters.

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